Flexibility Premium in Marketable Permits

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Theory of externalities: Problems & solutions

Problem: The problem of air pollution (so-called negative externalities) and the associated market failure had long been a part of the microeconomic theory. Economists saw pollution as the consequence of an absence of prices for certain scarce environmental resources.

Solution: Economists prescribed the introduction of surrogate prices in the form of unit taxes or "effluent fees" to provide the needed signal to economize on the use of this resource (such as cleaned air).

Motivation: Polluting agents need to be confronted with a price (equal to the marginal external cost of their polluting activities) to induce them to internalize (at the margin) the full social costs of their pursuits.

Form: Taxes, subsidies and marketable permits.

Today: Emission permits are considered the most cost-effective form to achieve environmental targets. Therefore, they have become the industrial world's standard tool for addressing externalities.

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CO_2 abatement alternatives

In a pollution-constrained economy where polluting companies are subject to environmental regulations that cap their noxious emissions, each firm faces a basic choice from three main abatement alternatives:

1. trade marketable permits (short-term abatement option);
2. modify the production process which generates the emissions as a by-product (medium-term abatement option);
3. change the production technology (long-term abatement option).

However, typical medium- and long-term abatement measures are perceived as

- hardly feasible or simply not profitable compared to more flexible instruments;
- expensive and irreversible commitments lasting decades.

For instance, purchase of allowances can be adapted to changing conditions whereas a scrubber might be under-utilized if demand falls or, conversely, the cost of a scrubber might be excessive after a fall in the permit price.

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Substitution principle for abatement measures

- Chao and Wilson [1993] and Zhao [2003] framed their studies of marketable permits calling into question the principle of perfect substitution between permits (short-term) and abatement measures (long-term).
- Intuitively, trading permits and a production process modification are *equivalent* alternatives exclusively when both lead to equal pollution-emissions reduction for the same total costs.
- We should account for those situations where a firm can reverse the investment decision (McDonald and Siegel [1986] and Brekke and Øksendal [1994]).
- We should account for those realistic situations where a firm faces physical or technical constraints that allow the implementation of economic decisions only after a given time-interval (Bar-Ilan and Strange [1996] for investments and Øksendal [2005] for disinvestment).
- For these reasons, the price of marketable permits must include a premium that recognizes the value of their flexibility as compared to the alternative of (non-instantaneous and delayed) investments in abatement strategies that reduce the quantity of emissions

Taschini (2008) in a nutshell

- In this paper we evaluate the value of flexibility implicitly embedded in the price of marketable permits in the presence of reversible pollution reduction investments.
- This model can support decision-makers in relevant companies in identifying the optimal level (time) for undertaking a (ir)reversible abatement measure. Such a modification of the production process is evaluated in the presence of delays in the implementation of the investment processes.
- We propose an infinite-time horizon model where a risk-neutral firm is subject to environmental regulations from time zero up to T. The firm maximizes its expected discounted pay-off flow and constantly emits α units of pollution at each instant.
- At each time $(t, 0 \leq t \leq T)$, the firm can either undertake a modification of the production process or purchase at the price P_t the necessary emission permits (purchased at time T).
- This paper extends Chao and Wilson [1993] and nests the model of Bar-Ilan and Strange [1996].

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Price of emission permits

The permit price P_t is then the value which makes the firm indifferent between the two choices:

$$\underbrace{V_t - e^{\rho(T-t)}[\alpha(T-t)] \cdot P_t}_{\text{No modification - permit purchase}} = \underbrace{V_t^m}_{\text{Modified net operating profits}}$$

Lemma.(Taschini [2008]) Purchasing permits at time t is equivalent to undertaking a reversible and costly modification of the production process at time t if, and only if, the price of the permits is

$$P_t = e^{\rho(T-t)} \cdot \frac{V_t - V_t^m}{\alpha \cdot (T-t)},$$

where V_t and V_t^m are defined in equation (1), $V_t > V_t^m$.

If the firm undertakes a reversible and costly modification of the production process at time t (V_t), then an equivalent (*substitute*) reduction of pollution by trading permits must corresponds to a purchase at time T of $\alpha \cdot (T-t)$ permits for a unit-price of P_t.

Price of emission permits

In light of our discussion, the permit price P_t can be decomposed into two components:

$$
\begin{aligned}
P_t &= e^{\rho(T-t)} \cdot \frac{V_t - V_t^m}{\alpha \cdot (T-t)} \\
&= e^{\rho(T-t)} \cdot \frac{V_t - V_t^{m,nd}}{\alpha \cdot (T-t)} + \underbrace{e^{\rho(T-t)} \cdot \frac{V_t^{m,nd} - V_t^{m,d}}{\alpha \cdot (T-t)}}_{\text{Flexibility Premium}}
\end{aligned}
$$

- The emission permit price is equal to the (per unit) difference between production without modification and production with modification.
- The flexibility premium is the value lost under the abatement alternative due to delays in the implementation process.

Optimal reversible and delayed abatement policy

- We model optimal investment and disinvestment decisions as the valuation of a perpetual American option contract.
- At any time t a risk-neutral firm can undertake an abatement project yielding a new operating profit that depends on the new instantaneous cash flow $\{S_t^m, t \geq 0\}$:

$$dS_t^m = \mu S_t^m dt + \sigma S_t^m Z_t, \qquad S_0^m = x,$$

  where μ and σ are constants and $(Z_t, t \geq 0)$ is a Brownian motion defined on a filtered probability space $(\Omega, \mathcal{F}, (\mathcal{F}_t)_{t \geq 0}, \mathbb{P})$.
- We denote by V_t^m the expected sum of the discounted cash flows from t to infinity,

$$V_t^m = \mathbb{E}_t \left[\int_t^{\infty} e^{-\rho(u-t)} S_u^m du \right]. \tag{1}$$

  where the discount rate ρ is constant and $\mathbb{E}_t[\cdot]$ stands for the conditional expectation $\mathbb{E}[\cdot|\mathcal{F}_t]$.

Optimal reversible and delayed abatement policy

- Let h_I and h_D be, respectively, the entry and exit levels;
- Let τ^I and τ^D be stopping times which correspond to the delayed (Parisian) criterion with time-windows d_I, d_D:

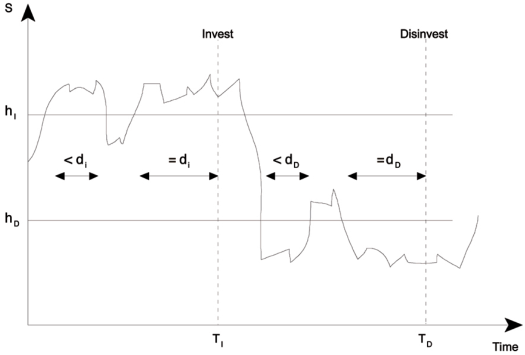
$$\begin{aligned} g_t^{V_0,h}(V^m) &= \sup\{s : s \leq t, V_t^m = h | V_0^m = x\}, \\ \tau^I_{(V_0,h_I),d}(V^m) &= \inf\{t \geq 0 : t - g_t^{V_0^m,h_I} \geq d_I, V_t^m \geq h_I | V_0^m = x\}, \\ \tau^D_{(V_0,h_D),d}(V^m) &= \inf\{t \geq 0 : t - g_t^{V_0^m,h_D} \geq d_D, V_t^m \leq h_D | V_0^m = x\}; \end{aligned}$$

  So, τ_I (τ_D) represents the first instant when the process V_t^m has consecutively spent d_I (d_D) units of time above (below) a specific threshold.
- Let C_I and C_D represent the investment and disinvestment costs.
- Because we are in the perpetual case, the investment and the disinvestment decisions will occur at the first instant when V_t^m hits some constant optimal threshold h_I^* or respectively h_D^*.

Graphical interpretation of the problem

- The firm maximizes the present value of its opportunities, namely it solves the following problem:

$$\max_{h_D \leq h_I,\ V_0^m \leq h_I} \mathbb{E}_0 \left[e^{-\rho\tau_I} (V_{\tau_I}^m - C_I)\, 1_{\{\tau_I < \infty\}} + e^{-\rho\tau_D} (C_D - V_{\tau_D}^m)\, 1_{\{\tau_D < \infty\}} \right]$$



Solution of the Problem

To solve the problem, we rely on the general results obtained in Costeniuc, Schnetzer and T. [2008]. In particular, we use

- the Laplace transform of the delayed investment (disinvestment) time;
- the moment generating function for the process V_t stopped at the delayed investment (disinvestment) time;
- and we adopt the following notation: $b = \frac{\mu - \frac{\sigma^2}{2}}{\sigma}$,

$$\theta_1 = \frac{-b + \sqrt{2\rho + b^2}}{\sigma} \quad \text{and} \quad \theta_2 = \frac{-b - \sqrt{2\rho + b^2}}{\sigma}.$$

Also, we define $\phi(z)$ as the moment generating function:

$$\phi(z) = \int_0^\infty x \exp(zx - \frac{1}{2}x^2) dx.$$

Solution of the Problem

Combining the results obtained in Costeniuc et al. [2008] and using the analytic solution to the optimal "entry" and "exit" levels obtained under the delayed investment criterion, we can re-write the maximization problem $VS(V_t^m)$ as:

$$\max_{h_d \le h_i} \left(\frac{V_0}{h_i}\right)^{\theta_1} \frac{\phi(b\sqrt{d_i})}{\phi(\sqrt{(2\rho+b^2)d_i})} \left\{ h_i \frac{\phi(\sqrt{d_i}(\sigma+b))}{\phi(b\sqrt{d_i})} - C_i + \right.$$

$$\left. + \left(\frac{h_i}{h_d}\right)^{\theta_2} \frac{\phi(-\sqrt{(2\rho+b^2)d_i})}{\phi(\sqrt{(2\rho+b^2)d_d})} \frac{\phi(-b\sqrt{d_d})}{\phi(b\sqrt{d_i})} \left(C_d - h_d \frac{\phi(-(b+\sigma)\sqrt{d_d})}{\phi(-b\sqrt{d_d})} \right) \right\}$$

$VS(V_t^{m,nd})$ represents the (instantaneous) maximization problem, i.e. when $d_I = d_D = 0$, whereas $VS(V_t^{m,d})$ represents the maximization problem under the delayed criterion, i.e. when $d_D > 0$ and $d_I > 0$.

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Premium for the flexibility

Theorem.(Taschini [2008]) Consider a company which has two pollution abatement measures at its disposal: trading permits or modifying the production process. The premium θ_t for the flexibility embedded in the price for marketable permits at time zero is:

$$\theta_t = e^{\rho\cdot(T-t)} \cdot \frac{VS^*(V_t^{m,nd}) - VS^*(V_t^{m,d})}{\alpha\cdot(T-t)}.$$

- When the modification of the production process can be implemented instantaneously, trading permits is equivalent to the pollution abatement measure.
- However, the presence of implementation delays makes production modification an attractive alternative if, and only if, a company is sufficiently compensated.
- Implementation delays significantly increase the emission permit price.
- Irreversibility significantly increases the emission permit price.

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A graphical interpretation of the premium

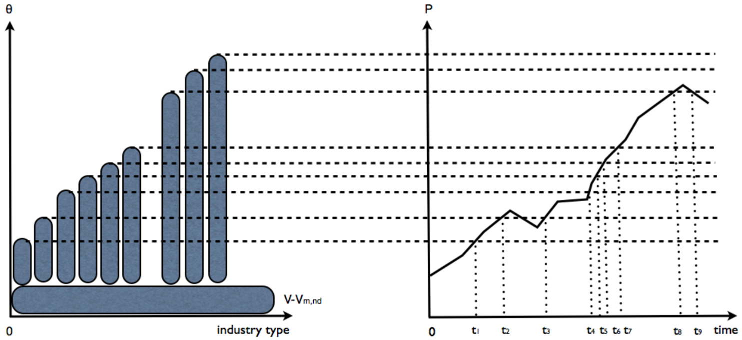

Figure: Premia lined-up per type of industry (left diagram). An hypothetical chart of the permit price (right diagram). The opportunity to kick-in a technology abatement in some industries might never occur.

Model implications

We now investigate the sensitivity of the premium for the flexibility, θ, and assess its likely magnitude for a given set of parameters.

d	0	2	4
0	0	0.0151	0.0285
3	3.5083	3.5253	3.5405
5	5.9422	5.9604	5.9767

Table: Premium benchmark case. The parameters we used are $\rho = 0.13; \mu = 0.05; \sigma = 0.40; C_D = 50; C_I = 170; V_0 = 100; \alpha = 1.$

When $d_I = d_D = 0$ trading permits and production modification are perfect substitutes. This implies, first, that the company is indifferent in undertaking an instantaneous modification of the production process or purchasing the needed amount of permits and, second, that the firm is not requiring a premium, i.e. $\theta = 0$ (upper-left corner of the tables).

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It is unsurprising to observe that the shorter (longer) the time-windows the more (less) attractive is the modification of the production process to the company.

d	0	2	4
0	0	0.0151	0.0285
1	1.1198	1.1355	1.1496
2	2.3015	2.3179	2.3326
3	3.5083	3.5253	3.5405
5	5.9422	5.9604	5.9767
6	7.1531	7.1719	7.1887
8	9.5365	9.5564	9.5743

Table: Premium for $d_l = \{0, 1, 2, 3, 5, 6, 8\}$. All other parameters being equal.

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Optimal instantaneous irreversible investment value h_{II}^*, and delayed optimal investment h_I^* and disinvestment h_D^* values.

		$d_I = d_D = 3$		$d_I = d_D = 5$	
σ	h_{II}^*	h_I^*	h_D^*	h_I^*	h_D^*
0.05	282.91	232.21	52.01	209.73	52.44
0.15	326.18	219.05	55.40	189.07	58.82
0.25	393.23	213.28	56.96	173.38	64.26
0.35	478.20	209.69	58.18	160.05	69.89
0.40	527.17	208.07	58.84	153.79	73.00

1. An increase in uncertainty delays instantaneous irreversible investments, increasing the instantaneous investment threshold.

2. In the presence of implementation delays, conventional findings on the effect of the uncertainty of the underlying process on investment and disinvestment are reversed. A higher volatility of the underlying process hastens both investment and disinvestment.

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When $d_D \to \infty$, the level h_I^* converges to

$$h_{OI}^* = \frac{\theta_1 C_I}{\theta_1 - 1} \frac{\phi(b\sqrt{d_I})}{\phi((b+\sigma)\sqrt{d_I})},$$

where h_{OI}^* represents the optimal investment threshold for time-window d_I while disinvestment is not possible.

1. The required premium for irreversible investments (θ_{OI}) is larger than the premium for reversible investments (θ_D).

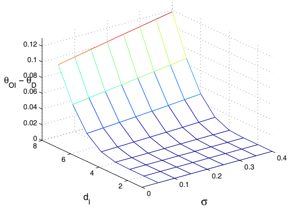

Figure: Plot of the difference between θ_D and θ_{OI}. These values are respectively the premia for reversible and irreversible investments .

Conclusions

- When the modification of the production process can be implemented instantaneously, trading permits are equivalent to the pollution abatement measure (up to the total abatement and purchasing costs)
- On the contrary, the price of marketable permits should include a premium representing the discounted expected value of the greater flexibility that emission permits provide, compared to the (ir)reversible and delayed commitments required by modifying the production process.
- We derive an analytic solution of the premium for the flexibility embedded in marketable permits extending Chao and Wilson [1993]. This model nests the model of Bar-Ilan and Strange [1996].
- This analysis can be used in the market design process. Different parameters sets could be implemented testing whether the policy outcome is consistent with the planners objective in terms of affected industries and induced technology change.

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